Energy and Buildings 62 (2013) 514–521

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Illumination control of LED systems based on neural network model and energy optimization algorithm

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ARTICLE INFO

Article history:
Received 10 August 2012
Received in revised form 15 March 2013
Accepted 18 March 2013

Keywords:
Intelligent lighting control
Neural network
Constrained nonlinear optimization
LED system

ABSTRACT

Lighting constitutes a large proportion of the main energy consumption loads of a building; energy-efficient lighting control is an important topic to be addressed in achieving green building requirement. Within a building, huge amount of lights are being deployed in a distributed manner which poses great challenge in achieving energy saving and personalized lighting control. In this paper, the objective is to satisfy table illumination preference of each office user while minimize energy consumption of the overall lighting system by optimizing the illumination levels of the distributed luminaires. A holistic and scalable neural network model is developed to represent the complex relationship between dimming levels of luminaires and measured illuminance on the table. Based on the developed model, a lighting energy optimization algorithm is proposed to achieve energy saving while having personalized lighting control. The proposed model can serve as a base model for the improved artificial light and even daylight control system in the future study.

1. Introduction

With rapid urbanization trend in all cities in the world, there are many challenges to ensure that each city continues to be a livable place. In any building environment, there exists plenty of opportunity to obtain energy conservation. Lighting constitutes 20–38% of energy consumption in commercial buildings in the United States [1]. It is important to explore lighting approaches and technologies to save energy.

Solid lighting technology like Lighting Emitting Diode (LED) is cost-competitive and energy-efficient and has large potential in replacing the traditional lightings such as fluorescent and hydrogen lamps [2]. Since dimming levels of a luminaire are related to the power it consumes, dimmable LED luminaires have great advantages in the energy efficient lighting system.

Some studies [3–5] have shown that energy consumed by lighting can be conserved by designing an indoor lighting control system with dimming capability. In [5], Users were able to control the lights and adjust the illuminance of their tables, but the ability to control the lighting did not put users in a more positive mood or affect the performance on the task. Lighting simulation model had been used to simulate the indoor illuminance in [6–8]. In [9], simulation and neural networks were used to facilitate a responsive lighting control strategy. The objective of [10] was to investigate the accuracy of simulating the illuminance distribution from lighting and the electrical lighting consumption of an exist atrium building. Researchers of [11] compared the energy savings and effectiveness of combinations of occupant detection, light dimming and switching techniques in private offices. An Excel application in [12] was developed to calculate illumination levels and energy impacts of a building.

The approaches for rendering illumination have been discussed in several studies [13–16]. In [17], researchers used Genetic Algorithm to real-time predict natural light levels at chosen points within a room. A fuzzy controller was developed in [18] to maintain the lighting illuminance level suitable for robotic manipulation in dynamic environments. In [19], the control of direct sun block to meet the workplane illuminance level was implemented using custom designed blind. In [20], a method was proposed to estimate and disaggregate illumination contributions of incoming light and the different LED sources at the workspace plane. In [21], lighting control was formulated as a linear programming problem to minimize energy usage and meet occupants' lighting preferences at the same time.

Energy-efficient lighting control can contribute great energy saving in a building context, and especially, large common office spaces have great potential. Typically, in a lighting control system, dimmable luminaires are installed and light sensors and occupancy sensors are placed to measure the illuminance and user occupancy. Some researches use simulation software to carry out the lighting

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http://dx.doi.org/10.1016/j.enbuild.2013.03.029

configuration in the test bed to establish the relationship between lights and table illuminance [10]. The drawback of this approach is that the performance of the simulation software could not imitate the real environment totally. For some researches, they implemented a few luminaires and sensors that researchers do not need to divide into groups. When considering a large office space with multiple lights and sensors, researchers also could put lights and sensors into different groups by placing partitions among them [22]. However, in many common offices, there are usually multiple lights and no higher partitions. The illuminance of a table in a test bed can be easily affected by several luminaires and the number of luminaires and tables increases as the test bed becomes bigger, it is difficult to group the luminaires with sensors and to get the optimal control results. In this situation, more energy can be conserved if the solution can be improved. When using illuminance sensors to assist in the feedback lighting control, the brightness of lights is changing, sometimes tremendously, before the lights become stable and it will affect users' eyesight and working efficiency. And if illuminance sensors are placed on the office tables, they will affect the working users and vice visa, users may affect the function of sensors accidentally.

In this paper, dimmable LED luminaires are implemented in our test bed. We use neural network technique to map the relationship among dimming levels of luminaires and table illuminance. Our goal is to minimize lighting energy consumption by adjusting the luminaire dimming levels since dimming level of a LED luminaire is proportional to energy it consumes. We also satisfy users' various illumination preference and consider the non-office hour scenario when some tables are not occupied and more energy can be conserved. We use a nonlinear optimization method to obtain the optimal lighting performance and the minimum energy consumption. The neural network model we built is based on the mapping relationship between luminaire dimming levels and table illuminance. Thus, this model is currently applicable for artificial lighting control at night. In the future, we will establish a second model to map the relationship between day light and table illuminance and further combine it with the current model into a complete model for lighting control in the day time. In this paper, we only introduce this base model which presents the relationship between luminaire dimming levels and table illuminance.

This paper is organized as follows. In Section 2, we introduce the test bed for implementing the dimmable LED luminaires. The neural network method used for mapping the relationship among luminaires and table illuminance is presented in Section 3. The lighting optimization solution with numerical results is shown in Section 4. Conclusions are drawn in Section 5.

2. LED lighting control test bed

Our test bed is an 8.5 m × 8.2 m office with installation of 9 * 54 W LED luminaires and 5 * 19 W LED luminaires (Philips BBS360 1×LED3500 NW (special: DC-DC) Luminaire efficacy: 65 lum/W) on the ceiling. These luminaires are all DALI controlled. There are 12 tables in the office. The numbering for the tables is shown in Fig. 15. Since there are no high partitions between tables, luminaires can affect the illuminance of more than one table. The office lighting illuminance followed in this setup is to be between 320 and 500 lux. All the LED luminaires used are dimmable and they can be controlled by the central controlling computer. The dimming level of a luminaire is proportional to its power consumption. The goals of this lighting control system are to satisfy different table users' preference of illuminance and to minimize the overall power consumption of lighting during the office hour as well as non-office hour. During non-office hour, only the illuminance reference of the occupied tables will be considered and the optimization algorithm will calculate based on the measured illuminance information and determine the final dimming setting for all luminaires. Since the system uses overall control and optimization, no grouping among luminaires and tables is needed and minimized energy consumption will be achieved given that illuminance reference of each table is met. Our lighting control test bed is shown in Fig. 1. To show the illuminance distribution and isoline, a simulated test bed is created by using DIALux lighting simulation software, shown in Fig. 2. And the lighting layout is shown in Fig. 3.

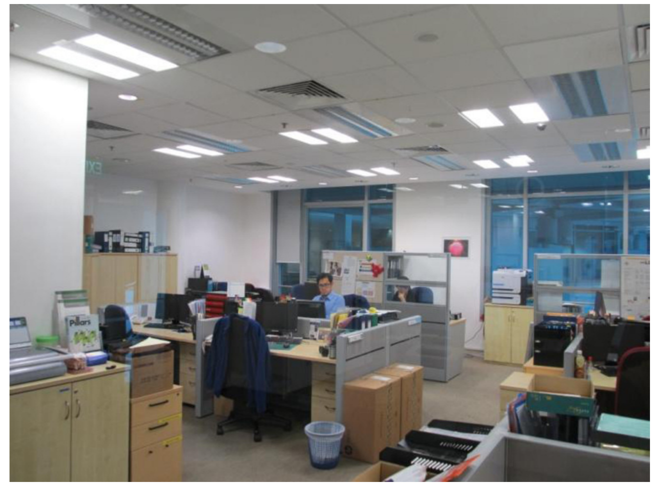

Fig. 1. The LED lighting control test.

3. System identification using neural network

Since luminaires and tables are hard to group in a large, open, complex lighting system, it is difficult to make control decisions for all luminaires when facing different illuminance preferences, especially during the non-office hour at night. The illuminance of one table is normally affected by more than one luminaire and traditional control methods are unable to handle it well. Before the lighting control, we need to get familiar with the test bed and figure out the relationship among luminaire dimming values and table illuminance by using the logged data from a portable lux meter inputted into the developed Dialux simulation model. The distribution of the lighting flux in the room can then be visualized and understood. If we treat the test bed as the plant to be controlled, luminaire dimming values are seen as inputs of the plant

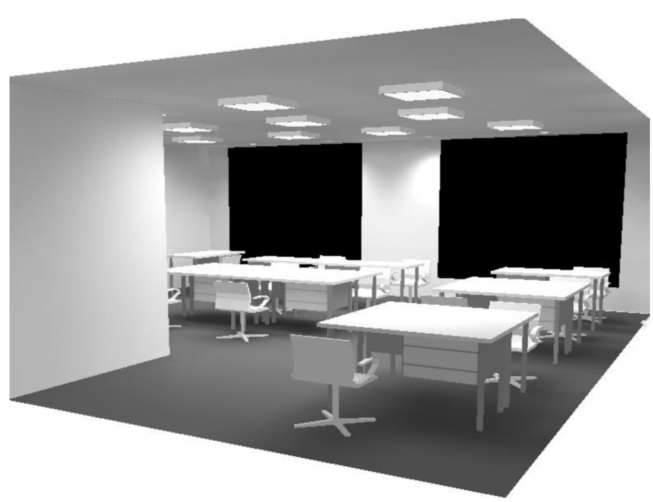

Fig. 2. A simulated test bed created using DIALux.